Hwang and Lee *International Journal of Geo-Engineering* (2015) 6:3
DOI 10.1186/s40703-014-0003-y

International Journal of Geo-Engineering
a SpringerOpen Journal

RESEARCH Open Access

The earth pressure on the rigid wall depending on the separation distance during the adjacent ground excavation

Yong-Sub Hwang* and Sang Duk Lee

* Correspondence: hys4047@naver.com
Department of Civil and Transportation Engineering, Ajou University, 206, World cup-ro, Yeongtong-gu, Suwon-si, Gyeonggi-do 443-749, Korea

Abstract

Background: When the ground would be excavated and retained adjacent to the existing structure, earth pressure acting on the rigid wall of the existing structure could be changed depending on its separation distance from the retaining wall, its wall friction, and the deformation of retaining wall.

Methods: Model tests were conducted in the uniform sandy ground for various separation distances and wall frictions. Test equipment consisted of the model test box, the rigid wall and the earth retaining wall. Location of the retained earth wall was varied. They were 0.4H, 0.8H and 1.2 H (H is the height of rigid wall). Friction angle of the rigid wall was varied. They were 0, $\varphi/3$, $2\varphi/3$.

Results: The earth pressure on the rigid wall was changed under the influence of the deformation of retaining wall, the separation distance of the retaining wall, and the friction of rigid wall. It was found out that the separation distance has more effects on the earth pressure reduction than that of the wall friction.

Conclusions: Change of earth pressure on the rigid wall induced by the ground excavation adjacent to it was affected by the friction of rigid wall, the separation distance, and the displacement of earth retaining walls. Earth pressure on a rigid wall was reduced in a larger amount when the wall friction of rigid wall increased.

Keywords: Wall friction angle; Retained earth wall; Ground excavation; Rigid wall

Introduction

When a ground is excavated and retained adjacent to the rigid wall of the existing substructure, the earth pressure acting on it could be changed.

Earth pressure on the rigid wall could be changed depending on the separation distance between retaining wall and rigid wall, the deformation of retaining wall and the wall friction of rigid wall (Lee 2014). Many studies have been conducted on the earth pressure acting on the retaining wall induced by the ground excavating adjacent to the existing structure (Oh and Lee 2010; Terzaghi 1934). But it is hard to find the studies on the variation of earth pressure on the existing structure induced by the ground excavation adjacent to it.

In this study, the model tests were performed in a sandy ground in order to find out the variation of earth pressure acting on the rigid wall of the existing substructure when the retained earth wall deformed adjacent to the rigid wall. The separation distance of the retaining wall to the rigid wall, the deformation of retaining wall, and the

Table 1 Test cases and test conditions

Test conditions	Test cases
Separation distance between the rigid wall and the earth retaining wall (H : height of rigid wall)	0.4H, 0.8H, 1.2H
Wall friction	0°, φ/3, 2φ/3

wall friction of rigid wall were varied. The test equipment consisted of the model test box, the rigid wall, and the retained earth wall. The uniform sandy model ground was constructed by sand curtain method, which was a kind of sand raining method. The wall friction of the rigid wall was varied. They were 0, ϕ/3, 2ϕ/3.

Laboratory model test

Case of model test

In the model tests, the earth pressure acting on the rigid wall was measured. In the tests, the separation distance of the retaining wall from the rigid wall and the wall friction of rigid wall were varied. The detailed conditions of model tests are described in Table 1.

Test ground

Test ground was built by natural Jumunjin quartz sand. The sand curtain method was applied to obtain the uniform ground condition.

1) soil properties

Model test ground was built by poorly graded sand (SP in USCS). whose relative density was Dr = 74.8%. Its particle size distribution curve is shown in Figure 1. Physical properties of the model ground are indicated in Table 2.

Internal friction angle (ϕ) of test ground was 38° as presented in Figure 2.

2) wall friction of the rigid wall

Friction between the rigid wall and the test ground was simulated by attaching the sand paper to the face of rigid wall. Commercial sand paper was used, which was manufactured in ISO/FEPA P-scale by ISO6344.

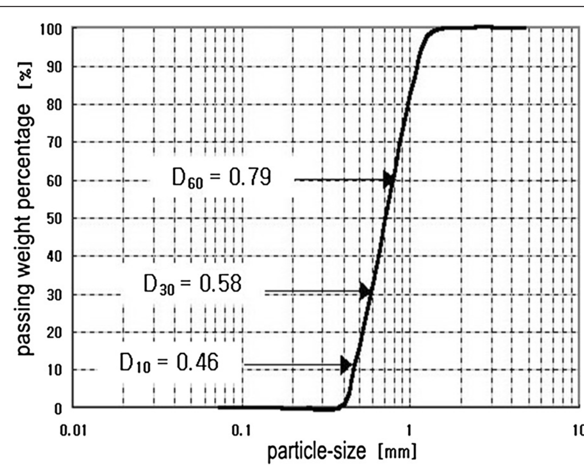


Figure 1 Particle-size distribution of the model ground.

Table 2 Physical properties of the model ground

Particle-size distribution	D_{10}= 0.46, D_{30} = 0.58, D_{60} = 0.79, C_u = 1.71, C_c = 0.93
Dry unit weight (kN/m^3)	γ_{dmax} = 17.9
	γ_d = 16.9
	γ_{dmin} = 14.6
Specific gravity	2.61
Relative density (%)	74.8
USCS	SP

Model tests were performed to the various wall friction angles, which were 0°, ϕ/3 (13°), 2ϕ/3(25°). Wall friction angle depending on the roughness of the commercial sand paper is indicated in Table 3.

Friction angle between the test ground and the sand paper with various roughnesses was measured in the preliminary shear tests. Wall friction angle ϕ/3 and 2ϕ/3 was achieved by attaching the sand paper P320 and P80 by ISO6344 at the face. Wall friction angle 0° could be achieved by attaching the thin PE (poly ethylen) film on the rigid wall with greece oil.

Model test apparatus

The test apparatus consisted of the model test box, the rigid wall, and the earth retaining wall. The model test box had the size of 180cm (length)*90cm (height)*30cm (width). The rigid wall was installed in the test box and the retaining wall was set with the various separation distances at the rear side of rigid wall.

The bottom of retaining wall was hinged at the bottom of test box in order to induce the Rankine's earth pressure condition.

The detailed dimensions of the experimental apparatus are presented in Table 4 and Table 5.

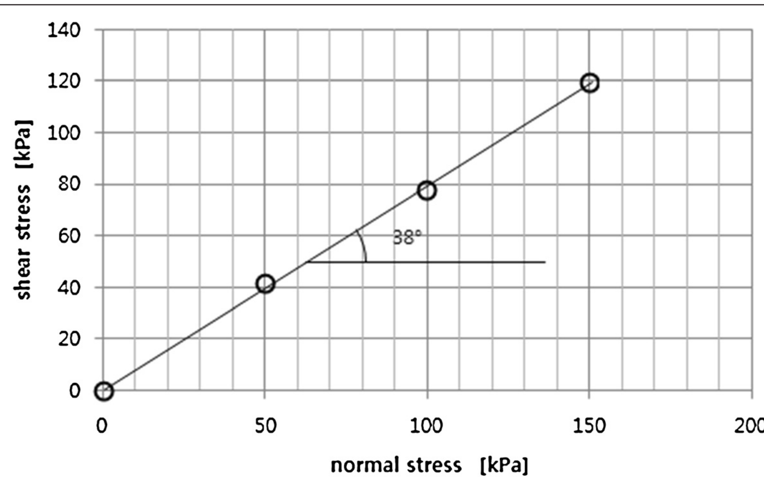


Figure 2 The result of the direct shear test.

Table 3 Wall friction of rigid wall

Surface condition	Wall friction angle (δ)	
PE film	0°	0°
P320 (sand paper)	13°	φ/3
P80 (sand paper)	25°	2φ/3

Measurement

The rigid wall was composed of 10 pieces in order to measure the distribution of earth pressure. Every piece was connected to two load cells.

Details of measuring instruments are presented in Table 6 and the measuring system is indicated in Figure 3.

Test procedure

Earth pressure acting on the rigid wall during the excavation of the ground adjacent to it was measured. The rigid wall and the retaining wall were installed in the model test box (Figure 4 (a)). Separation distance of the earth retaining wall from the rigid wall was varied. They were 0.4H, 0.8H, 1.2H (H: height of rigid wall). Sandy ground was built in the space between the rigid wall and the retaining wall (Figure 4 (b), (c)).

Wall friction angle of the rigid wall was varied. They were 0°, ϕ/3, and 2ϕ/3. Each experiment is presented in Figure 5. Rankine's active state was produced by rotating the retaining wall. Earth pressure on the rigid wall was measured during the rotation of the retaining wall (Figure 4 (d)).

Results

Earth pressure acting on the rigid wall depended on the separation distance, the wall friction angle, and the horizontal displacement of earth retaining wall. They are presented in Figure 6, in which s is the horizontal displacement of the top of retaining wall.

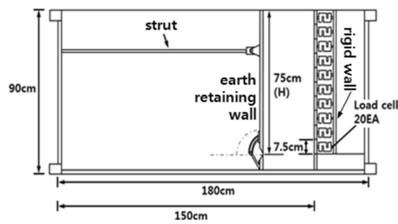
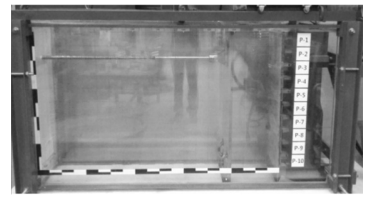
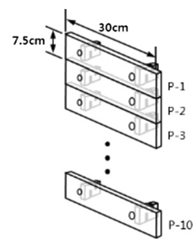
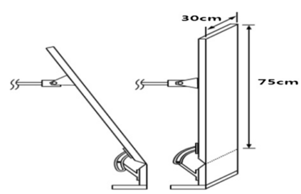
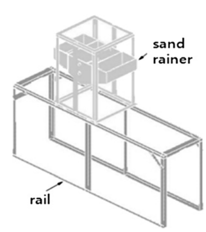
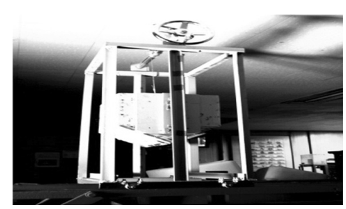
Earth pressure acting on the rigid wall

The measured earth pressure acting on the rigid wall under the influence of separation distance, wall friction, and the horizontal displacement are given in Table 7 and Figure 6.

Table 4 Dimensions of the test apparatus

Apparatus	Dimensions	Material
Model test box	◦180cm(length)×90cm(height)×30cm(width)	◦ steel plates(300mm) ◦ steel flat bars
Rigid wall	◦ 30cm(length)×7.5cm(height)×2.0cm(thickness) : 10ea segment ◦ load cell : 2ea per 1 segment , 20ea	◦ bakelite : E=147,000kgf/cm^2, EI=159kgfcm^2
Earth retaining wall	◦ 30cm(length)×75cm(height)×2.0cm(thickness) ◦ installation of hinge ◦ screw bar for horizontal displacement : D=10mm, L= 150cm	◦ bakelite : E=147,000kgf/cm^2, EI=159kgfcm^2
Sand curtain method	◦ 30cm(length)×130cm(height)×30cm(width)	◦ steel plate

Table 5 Test apparatus

<table>
<tr><th>Apparatus</th><th>Diagram</th><th>Picture</th></tr>
<tr><td>Model test box</td><td>
</td><td></td></tr>
<tr><td>Rigid wall</td><td>
</td><td></td></tr>
<tr><td>Earth retaining wall</td><td>
</td><td></td></tr>
<tr><td>Sand raining apparatus (sand curtain method)</td><td>
</td><td></td></tr>
</table>

Rankine's active failure state was induced by changing the slope of the earth retaining wall from 90 to 60 degrees.

Test results are as followings.

1) effect of wall friction of rigid wall

As the horizontal displacement of earth retaining wall increased, the earth pressure on the rigid wall was reduced. The amount of earth pressure reduction depended on the separation distance. The measured earth pressure acting on the rigid wall under the influence of wall friction is given in Figure 7.

Table 6 Details of measuring instruments

Item	Sensor	Capacity	Number	Data logger
Earth pressure	load cell	100kgf	20	TDS-303

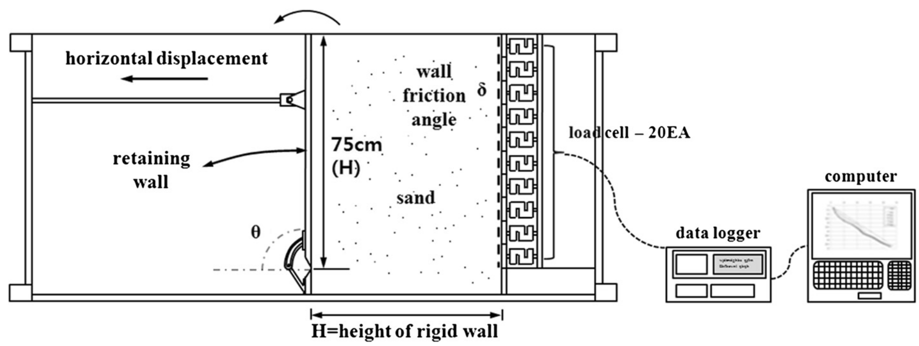


Figure 3 Measuring system.

If the wall friction was zero, (i.e. $\delta = 0$), the earth pressure on rigid wall was reduced in an amount of 19% ~ 27% in the separation distance of 0.4H, 14% ~ 16% in 0.8H, and 11% ~ 12% in 1.2H. Even if the active failure occurred, declination of earth pressure reduction curve was not significant.

When the wall friction was $\phi/3$, earth pressure was reduced in an amount of 14% ~ 21% in the separation distance 0.4H, 9% ~ 10% in 0.8H, and 10% ~ 11% in 1.2H. If the wall friction was $2\phi/3$, earth pressure was reduced in an amount of 14% to 21% in the separation distance 0.4H, 11% ~ 13% in 0.8H, and 9% ~ 10% in 1.2H. Therefore, we could say that high wall friction and large displacement of earth retaining wall brought less earth pressure reduction, even if active failure occurred.

2) effect of the separation distance

Earth pressure on the rigid wall decreased as the separation distance increased. Earth pressure on the rigid wall decreased about 14% ~ 17% in the separation distance 0.4H, 8% ~ 16% in the separation distance 0.8H, and 9% ~ 12% in the separation distance 1.2H. The measured earth pressure acting on the rigid wall under the influence of separation distance is given in Figure 8.

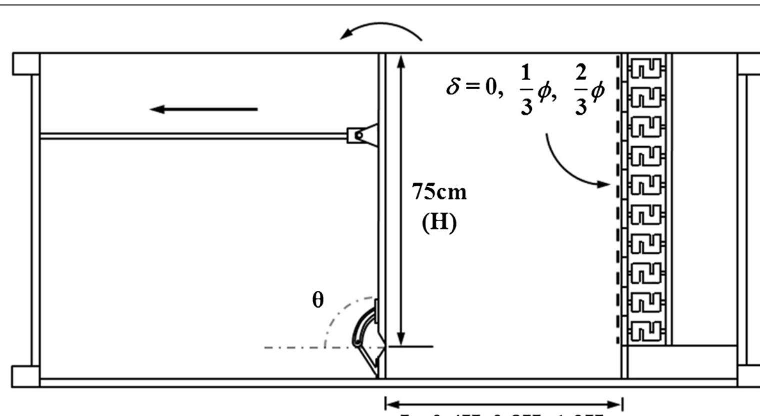
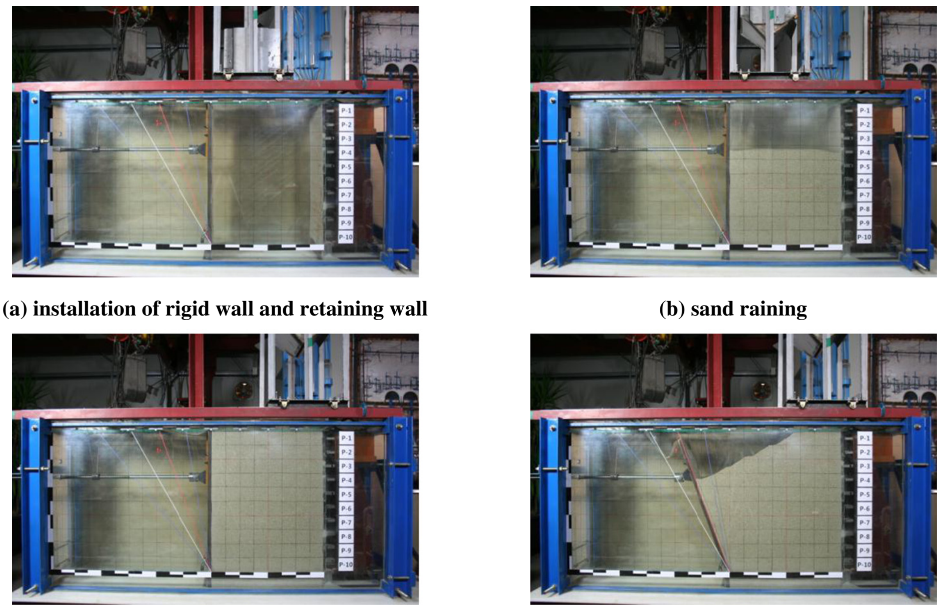


Figure 4 Test variables.



(a) installation of rigid wall and retaining wall

(b) sand raining

(c) initial state

(d) rotating the retaining wall

Figure 5 Test procedures.

As the earth retaining wall was located in a larger distance from the rigid wall, earth pressure was reduced less. In case of separation distance 1.2H, the amount of earth pressure reduction was similar to each other. Variation of pressure ratio, which was defined as earth pressure divided by earth pressure at rest, was gradually reduced to the residual value, which was depending on the wall friction.

As the retaining wall was located closer to the rigid wall, the earth pressure was reduced in an amount of 21% ~ 27% depending on the wall friction. As the earth retaining wall was located in a larger distance from the rigid wall, the earth pressure was reduced in an amount of 10% ~ 12% depending on the wall friction.

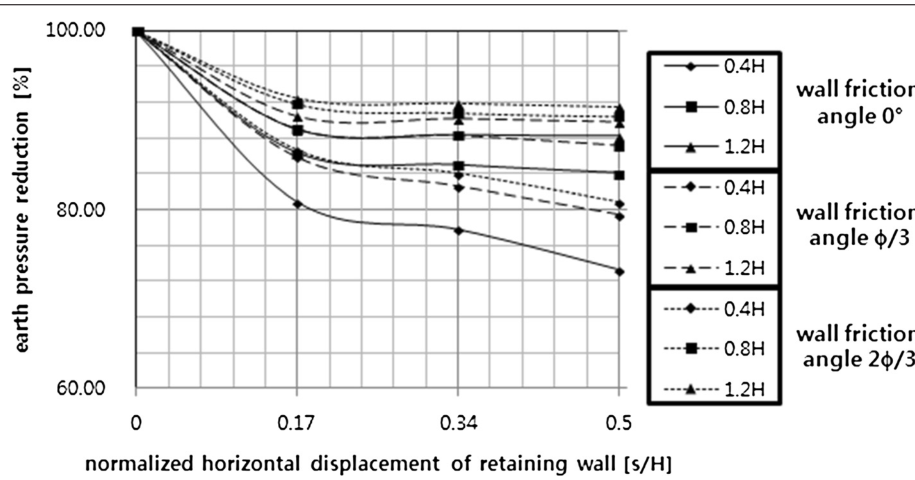


Figure 6 Earth pressure reduction acting on the rigid wall.

Table 7 Earth pressure reduction acting on the rigid wall (unit: %)

s/H		0	0.17	0.34	0.5
0.4H	0	100	80.83	77.73	73.21
	φ/3	100	85.85	82.61	79.43
	2φ/3	100	86.63	84.01	80.78
0.8H	0	100	86.30	84.94	84.03
	φ/3	100	89.01	88.30	87.19
	2φ/3	100	91.80	90.81	90.41
1.2H	0	100	88.97	88.37	88.24
	φ/3	100	90.47	90.21	89.84
	2φ/3	100	92.49	91.90	91.51

As the separation distance of the earth retaining wall became smaller, the effect of wall friction on the earth pressure on the rigid wall became larger. In case of separation distance 1.2H, earth pressure was reducted about 11% ~ 15%. Therefore, effect of the separation distance on the earth pressure was larger than that of the wall friction.

3) effect of the deformation of earth retaining wall

The earth pressures on the rigid wall depending on the deformation of the earth retaining wall are presented in Figure 9 (a), (b) and (c). The earth pressure decreased to the residual value when the retaining wall deforms.

As the retaining wall deforms more and more, earth pressure on the rigid wall decreased and then converged to a residual earth pressure. As the separation distance became larger, the earth pressure variation rate converged rapidly in a small horizontal displacement and the residual earth pressure became larger.

The residual earth pressure on the rigid wall for the various separation distances are presented in Figure 10 (a), (b) and (c).

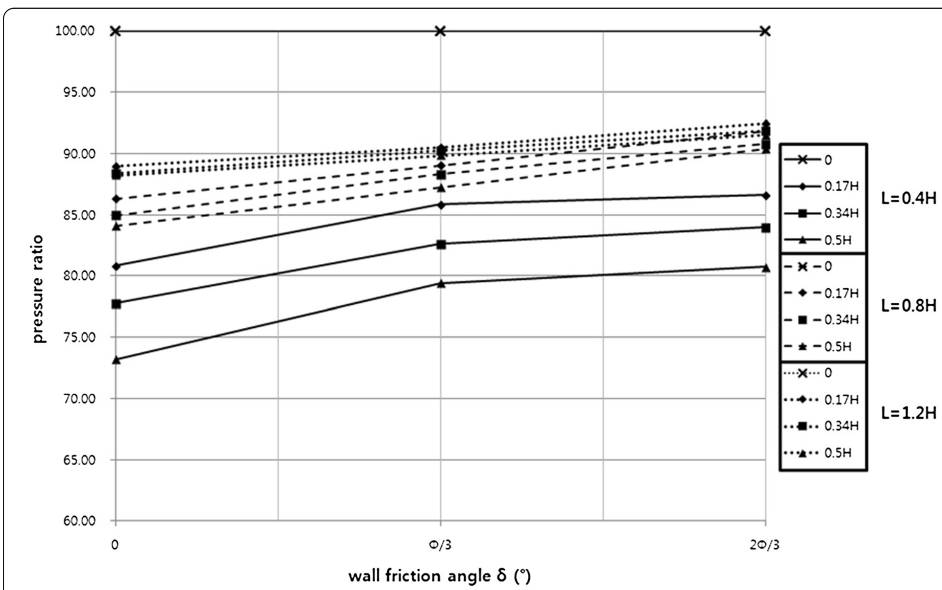


Figure 7 Relationship of earth pressure and wall friction angle for various separation distance.

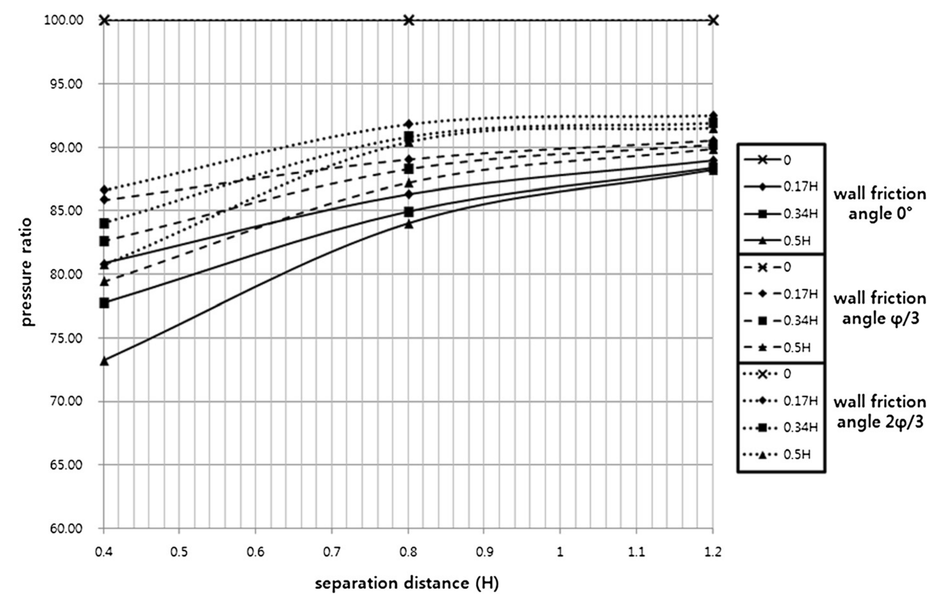
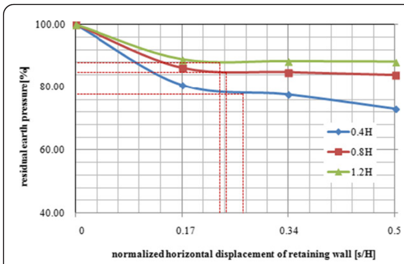
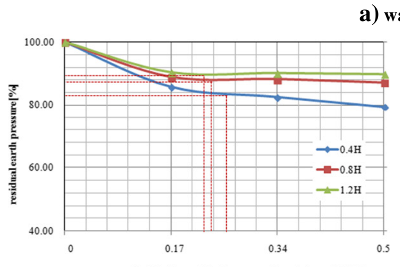


Figure 8 Wall friction angle-separation distance diagram.



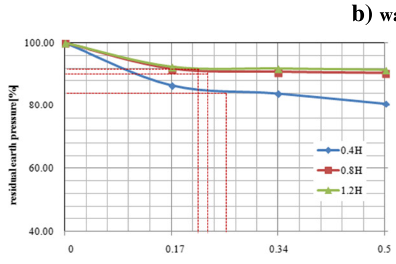
separation distance	0.4H	0.8H	1.2H
normalized horizontal displacement of retaining wall	0.27	0.24	0.23
residual earth pressure	77.65	84.59	87.59

a) wall friction angle 0°



separation distance	0.4H	0.8H	1.2H
normalized horizontal displacement of retaining wall	0.26	0.23	0.22
residual earth pressure	82.35	87.65	88.94

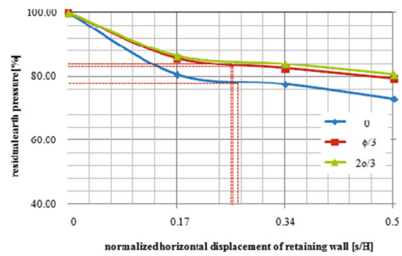
b) wall friction angle ϕ /3



separation distance	0.4H	0.8H	1.2H
normalized horizontal displacement of retaining wall	0.26	0.23	0.21
residual earth pressure	83.53	90.59	91.42

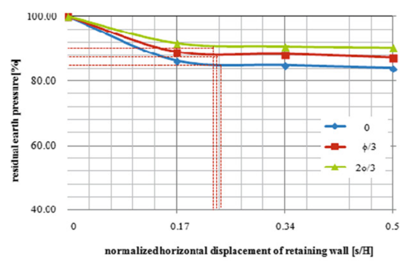
c) wall friction angle 2ϕ /3

Figure 9 Earth pressure reduction induced by the horizontal displacement of retaining wall.



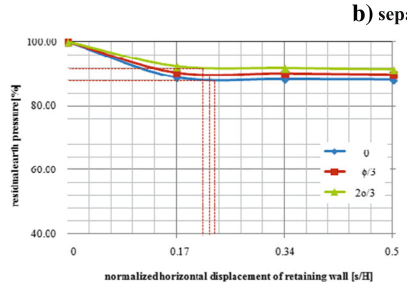
wall friction angle	0	φ/3	2φ/3
normalized horizontal displacement of retaining wall	0.27	0.26	0.26
residual earth pressure	77.65	82.35	83.53

a) separation distance 0.4H



wall friction angle	0	φ/3	2φ/3
normalized horizontal displacement of retaining wall	0.24	0.23	0.23
residual earth pressure	84.59	87.65	90.59

b) separation distance 0.8H



wall friction angle	0	φ/3	2φ/3
normalized horizontal displacement of retaining wall	0.23	0.22	0.21
residual earth pressure	87.59	88.94	91.42

c) separation distance 1.2H

Figure 10 Earth pressure reduction induced by the horizontal displacement of retaining wall.

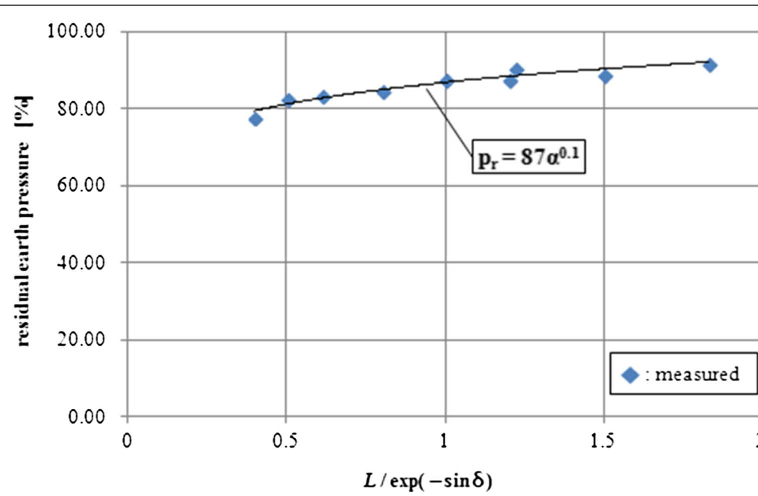


Figure 11 Ratio of the residual earth pressure.

As the wall friction angle increased, the earth pressure variation rate was converged in a small horizontal displacement of earth retaining wall.

3.2 Earth pressure depending on the separation distance

In this study, it was found that the earth pressure acting on the existing structure during the ground excavation adjacent to it was dependent on the separation distance and the wall friction angle. Ratio of the residual earth pressure to the earth pressure at rest p_r could be calculated by the proposed equation as follows:

$$p_r = 87\alpha^{0.1}$$

in which α is defined as $\alpha = L/e^{-\sin\delta}$, and $\boldsymbol{L}$ is a separation distance normalized by the height of rigid wall.

The calculated values from the proposed equation and test results are presented in Figure 11. For the proposed equation R-squared is 0.92.

Conclusion

In this study, the change of earth pressure on the rigid wall of the underground structure induced by the ground excavation near at hand was experimentally studied.

The distance between rigid wall and excavated earth wall, the wall friction of rigid wall, and the deformation of retained earth wall were chosen as experimental variables.

Results are as follows:

(1) Change of earth pressure on the rigid wall induced by the ground excavation adjacent to it was affected by the friction of rigid wall, the separation distance, and the displacement of earth retaining walls.
(2) Earth pressure on a rigid wall was reduced in a larger amount when the wall friction of rigid wall increased.
(3) If the separation distance is small, earth pressure on the rigid wall converged to a small residual earth pressure at a small displacement of the retaining wall.
(4) When the friction of rigid wall was large, the earth pressure on the rigid wall converged to a large residual earth pressure at a small horizontal displacement of retaining wall.
(5) Ratio of the residual earth pressure to the earth pressure at rest could be estimated from the wall friction angle and the separation displacement.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

Y-SH carried out all of the experiments with help from SDL. Both authors read and approved the final manuscript.

Received: 6 June 2014 Accepted: 11 December 2014
Published online: 26 February 2015

Reference

Lee, SD. (2014). Soil Mechanics. CIR, 359-360. (ISBN: 979-11-5610-038-6),
Oh, BJ, & Lee, SD. (2010). "Earth Pressure on a Rigid wall due to Loads Condition and Distance", 2010. *Journal of the Korean Geotechnical Society (KGS), 26*, 51–60. No.12.
Terzaghi, K. (1934). Large retaining wall tests. *Eng News Record, 112*, 136–140.